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Applied Research on Controlling Stored-grain Insects with Nitrogen

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Abstract: Under sealed conditions, oxygen was separated from the atmosphere by a homemade high – purity nitrogen generator for grain storage to generate high – purity nitrogen. High – purity nitrogen was dispersed and distributed uniformly in the bulk through re – circulation pipe under film. To control stored-grain insects, the concentration of nitrogen was maintained above 95% for at least 19 days, which made insects under long – term hypoxic circumstance and finally die for lack of the necessary amount of oxygen. In addition, oxygen concentration below 5% decreased the rate of wheat physiological metabolic activity, respiration, quality deterioration, and growth of grain – storage microbes. It increased wheat security in storage.

Key words: nitrogen, stored-grain Insects, controlled atmosphere storage (CA storage), applied research

Introduction

With the development of people's living standards, their concept of food consumption has changed from sufficent and good food to safe, nutritious and environment-friendly food, and Green Food is increasingly welcomed. Grain reserve is a state policy of guaranteeing social and economic development. The quality of stored-grain has directly affected the quality of people's life. Today's main technology of controlling insect in grain reserve is chemical fumigation. The pollution caused by this to grain can't be express quantitatively. In general, fumigation in grain is neither safe to grain or to operators.

As the disadvantage of chemical agents in controlling stored-grain insects is taken more seriously, some developed countries start to use alternative technology to replace chemical agents. Some of the economically developed countries, such as America, Japan, Russia and Australia, have gradually reduced the usage of chemical agents on stored-grain, and developed modern technologies of grain reserve towards integrated management including low temperature storage, CA storage, physical and biological storage, and made many studies on CO_2 CA storage. Canada, Japan and other countries in the world have also researched the technology controlling stored-grain insects with nitrogen.

Since 1998, the infrastructure facilities of grain reserve in China have made much headway. The central government invested much treasury bonds on construction of modern depots of State Grain with volume of 100 billions. It involves the application and extension of four new technologies for grain reverse, low temperature grain storage with grain cooler, computerized grain conditions control system, mechanical aeration and phosphine re-circulation fumigation, that promoted smooth development of research on new technology, equipment, techniques, instruments and method for oil and grain reserve.

At present, chemical fumigation technology, commonly used for stored-grain insects control, has advantages of killing insects quickly, thoroughly, economically, with labor-saving and so on, but also with its problems, increasingly resistance to phosphine, increasingly phosphine dosage, phase-out of methyl bromide, and limited use of dichlorovos. . In addition, chemical agents made chemical residues and pollution in stored grain, and damage people's health by long-term exposure.

The CO_2 CA storage could effectively control the stored-rain insects and decrease the rate of wheat physiological metabolic activity, respiration, quality deterioration, and growth of grain-storage microbes, but its cost was much higher than traditional fumigation, and four times higher than N_2 CA storage. Cost was the great obstacle that prevented its development and application.

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The Nanjing depot of state grain developed a new type of grain storage device, mobile high-purity nitrogen generator $ZCBGPN_29-30PSA$, in 2004, and researched N_2 CA storage technology in horizontal warehouses. The research achieved good results, promoted technical progress in grain storage sector, and played an important role in protection of people's health.

1 Materials and Method

1.1 Test Depot

1.1.1 N_2 CA storage: No. 20, horizontal warehouse, specification, 30m × 21m, grain height, 6m.

1.1.2 CO_2 CA storage: No. 19, horizontal warehouse, specification, 30m × 21m, grain height, 6m.

1.1.3 Gas tightness measurement: Surface of grain bulk was sealed with two layers PE sheeting; Vent opening and door were sealed with two grooves method; Gas tightness, measured according to negative atmospheric pressure 300 Pa back to 150 Pa, was more than 2 minutes.

1.1.4 Ventilation system: over – ground ducting, one machine, two groups of three ducts, ventilation pipe network 30cm under grain surface..

1.1.5 Equip with nitrogen and carbon dioxide detecting device and Grain monitoring system.

1.1.6 Insect monitoring device: Automatic insect monitor MCS – 180 with five transducers, five 400 scan lines, wireless transmission device with a transmit distance of more than 1000 meters.

1.2 Test Grain

Depot No.	Variety	Amount (tonne)	Insect and Number (Insects per square meter)	Water content (%)	Impurity (%)	Grain temperature (℃)			Garnered in time
						Upper layer	Middle layer	Under layer	
19	Middle – late hsien Rice	2169	10 *Sitophilus zeamais*	13.1	0.7	29	17.6	13.6	06.10
20	Middle – late hsien Rice	2120	10 *Sitophilus zeamais*	13.4	1	27.1	14.5	12.2	06.11

1.3 High-purity Nitrogen Generator

Nitrogen was separated from air by pressure swing adsorption. The generator had four parts, air purification, nitrogen generation, nitrogen output and nitrogen conveyor pipe in depot. It was a mobile device.

1.3.1 Air purification: To ensure the long – term stable operation of the N_2 generator, an adsorption tower as a part of the generator must be provided with clean and dry air. Thus it was necessary to remove water, dust and oil in air by certain filter before air entered the adsorption tower.

1.3.2 Nitrogen generation: Nitrogen of more than 99% purity was directly generated from adsorption tower by technology of pressure swing adsorption at speed of 30 – $60m^3/h$. Adsorption material was high-performance carbon molecular sieve.

1.3.3 Nitrogen output: To ensure the effective N_2 concentration in the test depot, the adsorption tower was equipped with N_2 monitoring device at the N_2 duct exit, and a gas analyzer was provided at the vent opening of depot.

1.3.4 Nitrogen conveyor pipe in depot: Nitrogen was promoted to dispersed and distributed uniformly in the bulk through a re-circulation pipe network under film.

1.4 Insects bags and monitoring device

1.4.1 Test insects: three kinds of representative insects cultured in lab, *Sitophilus zeamais*, *Rhyzopertha dominica*, *Cryptolestes ferrugineus*.

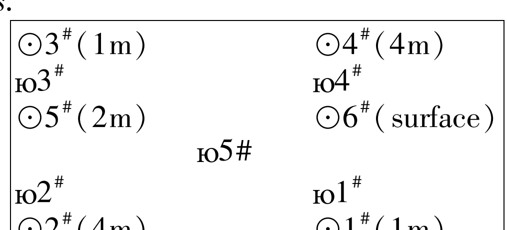


Figure. Drawing of distribution of insect bags and monitoring devices in No. 19, No. 20 depots
Note: "⊙" and "ю" represent insect bag and monitoring device, respectively.

1.4.2 Test insect bags: each bag filled

with 10 *Sitophilus zeamais*, *Rhyzopertha dominica*, and *Cryptolestes ferrugineu*, sealed and prepared for use.

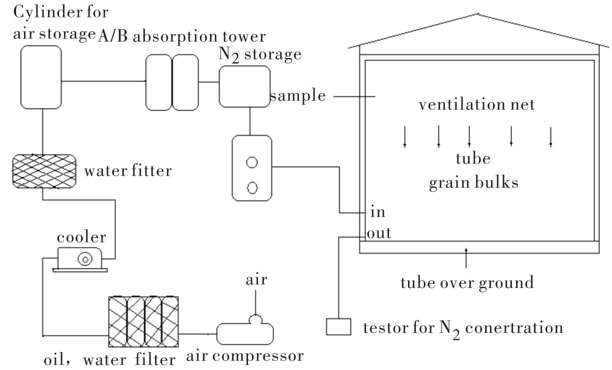
1.4.3 Insects bags and monitoring device were pre-buried as follows by in-depth slender

2 Test Procedure

Air → Compressor → Filter → Air tank → Adsorption Tower → N_2 tank → Pre-cooling device → Grain piles

Drawing of N_2 CA Storage Process

The N_2 CA storage device was tested then the high-purity nitrogen generator was started to generate and pump N_2 into test depot. The concentration of nitrogen was maintained above 95% for at least 19 days. The N_2 concentration was regularly measured. The high-purity nitrogen generator was started to add N_2 once the N_2 concentration fell below 95%.



3 Results

3.1 Observation of Insect Situation in Operation Interval of N_2 Supply System

See Table 1 for more details.

Table 1. N_2 concentration and insect behavior in No. 20 depot.

Time			umulative time of N_2 supply (h)	Change of N_2 content of different position in depot						Insect situation
Month	Day	Hour/minute		1	2	3	4	5	after Ventilation	
6	24	9:40	Start	/	/	/	/	/	/	Crept rapidly
6	24	20:40	17	82.1	82.5	83.7	82.5	85.2	85.4	/
6	25	19:40	37	89.8	88.4	89.3	89.4	90.4	90.3	/
6	26	23:40	62	95.6	95.8	96.6	96.4	96.6	96.9	Crept rapidly
6	27	20:40	71	96.3	96.5	96.6	96.7	97.2	97.8	/
6	28	9:40	71, pause	96.4	96.5	96.8	96.6	96.5	/	/
6	29	9:40	/	96.3	96.3	96.7	96.5	96.2	/	/
6	30	9:40	/	95.9	95.9	96.2	95.8	95.7	/	Crept rapidly
7	1	9:40	/	95.6	95.1	95.3	95.7	95.3	/	*Sitophilus zeamais slow down; other insect changed little*
7	2	9:40	/	95.1	94.8	95.0	95.2	94.9	/	
7	3	8:00	Continue	94.8	94.9	95.1	95.0	94.8	94.5	*Cryptolestes ferrugineus Crept rapidly*
7	4	8:00	95	95.9	95.6	96.1	95.8	96.7	97.6	
7	4	22:00	109, pause	96.8	96.4	96.5	96.7	97.3	97.6	*Rhyzopertha dominica move slowly*
7	5	8:00	/	96.5	96.4	96.3	96.8	96.6	/	*Sitophilus zeamais spot circumvolve*
7	6	8:00	/	96.3	96.4	95.8	96.3	96.0	/	*Rhyzopertha dominica roll around slowly*
7	7	8:00	/	95.8	95.8	95.7	95.4	95.8	/	*Cryptolestes ferrugineus slow down*
7	8	8:00	Continue	95.3	95.2	95.2	95.3	94.9	94.7	
7	9	8:00	133	95.8	95.7	96.2	95.7	96.4	97.1	*Sitophilus zeamais、Rhyzopertha dominica immobilized, Cryptolestes ferrugineus slightly move*

Time			umulative time of N_2 supply(h)	Change of N_2 content of different position in depot						Insect situation
Month	Day	Hour/minute		1	2	3	4	5	after Ventilation	
7	10	8:00	157, pause	96.8	96.9	96.4	96.7	97.2	97.8	
7	11	8:00	157	96.1	96.2	95.8	95.9	96.7	96.6	All insects immobilized
7	12	8:00	157	95.7	95.2	95.6	95.2	95.7	95.6	All insects immobilized
7	14	10:00	Open the depot, took out insects	94.8	95.1	94.9	94.5	94.7	/	No living insects

3.2 Control Test of CO_2 CA Storage

3.2.1 Checking Equipment

(1) Detected whether the CO_2 monitoring device and pneumatic valve on the detecting tube were in proper operation, and checked the CO_2 infra-red analytical instrument.

(2) Detected whether the pipeline for conveying CO_2 was in good operation and whether there was water in pipeline to ensure the security of stored-grain.

(3) Detected whether the valve, electromagnetic valve and electric valve on main pipeline worked normally.

(4) Detected whether the CO_2 tank, heating device for gas tank, pressure regulating device etc. can function normally

(5) Tested whether the half-life of gas tightness of test depot reached the standard requirement. If the half-life of gas tightness of test depot didn't meet the standard, the test depot was reconstructed

3.2.2 CO_2 CA storage

During the fumigation interval, control the temperature of CO_2 near the average level, maintain the amount of air flow at $200m^3/h$, keep the inner pressure of pipeline steady, adjust oil scale of pressure balance pipe to make the inner pressure of depot around 100 Pa. When the CO_2 concentration of upper layer in depot reached above 70%, closed the valve and stop the fumigation.

Based on results of everyday detection, we found 10% CO_2 concentration attenuation everyday in the first five days, after five days, the CO_2 concentration attenuation everyday was reduced to 5%. After 10 days, the CO_2 concentration in the upper layer was reduced to about 45%, however, the CO_2 concentration of the lower layer was about 80%. Because CO_2 concentration must be at least 45% during fumigation, so we used re-circulation fans to balance and maintain the CO_2 concentration above 45%. See Table 2 for more details about CO_2 concentration of No. 19 depot.

Table 2. Automatic Record of CO_2 concentration of No. 19 depot

Time	Upper layer					Middle layer					Lower layer					Average	Note
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5		
2007-6-8 21:21	71.8	71.8	72.5	72.4	71.3	72.0	71.5	72.5	72.3	72.0	71.9	70.9	72.4	71.1	71.4	73.8	
2007-6-9 8:46	72.0	70.9	71.9	68.5	56.3	72.3	71.0	69.8	68.6	59.4	59.3	56.6	53.4	55.9	49.6	63.7	
2007-6-10 8:38	67.6	67.0	67.3	73.8	50.4	68.4	61.1	56.5	72.5	51.8	43.0	38.8	37.5	43.0	41.1	55.9	
2007-6-11 8:17	64.5	70.4	68.5	79.1	50.4	65.5	57.5	55.3	68.4	51.0	43.3	39.9	38.5	37.1	41.6	55.3	
2007-6-12 8:18	64.5	70.4	66.5	79.1	50.4	65.5	57.5	55.3	68.4	51.0	41.3	39.9	38.5	37.1	41.6	55.1	
2007-6-13 7:54	70.3	76.9	68.8	88.3	58.5	71.4	64.4	62.3	65.3	58.4	48.5	46.5	44.6	42.8	48.8	63.8	2 hours re-circulation
2007-6-14 8:03	67.0	74.1	65.2	74.3	49.3	68.0	62.6	60.6	63.0	49.1	41.1	45.8	44.1	42.3	41.1	56.5	
2007-6-15 7:37	74.4	93.1	89.7	91.4	63.1	75.9	81.3	78.4	80.5	63.5	54.1	61.9	59.3	56.6	54.4	73.8	Added one ton of N_2
2007-6-16 7:48	71.6	78.8	79.6	78.3	53.3	64.5	67.5	65.5	67.6	53.1	45.6	50.5	48.9	47.0	45.5	63.2	

Time	Upper layer					Middle layer					Lower layer					Average	Note
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5		
2007－6－17 8:15	65.8	72.5	71.2	80.4	55.0	67.0	62.0	67.8	70.1	55.4	47.6	46.3	51.3	49.4	47.5	68.6	
2007－6－18 8:16	74.6	81.0	70.5	80.1	63.0	76.3	70.1	67.6	70.0	55.3	55.0	53.3	51.6	49.5	48.0	64.4	
2007－6－19 8:24	72.3	79.6	70.3	79.0	61.3	74.3	68.4	66.1	68.6	54.1	53.6	51.3	50.5	48.6	47.0	63.6	
2007－6－20 8:40	70.8	76.5	65.7	76.1	58.1	72.1	65.6	63.3	66.4	58.5	51.1	49.8	48.3	46.4	45.0	68.9	
2007－6－21 7:50	68.6	68.6	62.8	68.3	50.5	70.6	58.6	56.1	59.1	51.3	50.6	47.2	41.8	40.4	39.3	55.6	
2007－6－22 8:01	78.5	84.6	59.2	82.9	56.6	68.7	73.3	69.8	73.0	57.3	50.0	54.8	53.4	51.6	49.8	64.2	2 hours recirculation
2007－6－23 7:50	63.6	68.5	54.3	74.0	50.1	64.9	58.4	55.6	65.0	50.5	44.4	42.8	42.3	41.0	43.9	54.6	
2007－6－24 7:47	61.8	66.1	50.6	71.3	48.8	63.0	56.8	59.3	63.0	48.9	43.5	42.0	45.8	44.5	42.9	53.9	
2007－6－25 7:10	59.4	63.3	46.8	67.8	46.5	60.6	54.6	51.8	60.3	46.8	41.9	40.5	40.1	39.0	41.5	58.7	

4 Analysis

4.1 The results in Table 1 showed the insect bags pre-buried in No. 20 depot were taken out at July 14 and insects were reared at condition of RH75%, 28℃ for 15 d, and no living insects were found 15 days later. The results showed stored-grain insects could be effectively controlled by controlled atmosphere of N_2 at concentration above 95% for 19 d.

4.2 The results in Table 1 showed the death of stored-grain insects was a long process and different insects had different times to deaath. *Rhyzopertha dominica*, *Cryptolestes ferrugineus* and *Sitophilus zeamais* were relatively difficult to control, especially *Cryptolestes ferrugineus*, which survived more than 10 days, stared to die till the 13th day, and completely died from the 16th day, under condition of 96% N_2. To control the stored-grain insects completely, especially the insects in corner, the fumigation period was extended to 19 days. The results showed the N_2 CA storage in our study and traditional phosphine fumigation had the same fumigation period of 19 days.

4.3 Comparison of N_2 CA storage, CO_2 CA storage, and Phosphine recirculation fumigation under plastic sheeting (PRFPS). See Table 3 for more details.

Table 3. Comparison of N_2 CA storage, CO_2 CA storage, and PRFPS

Content \ Technology	N_2 CA storage	CO_2 CA storage	PRFPS
Principle	High concentration N_2 was generated by home-made high-purity nitrogen generator and then dispersed and distributed uniformly in the grain bulk through recirculation pipe under film. Long-term lack of oxygen causes the death of stored-grain insects.	Depot was sealed, and then filled with CO_2 by gas storage tank. CO_2 dispersed and distributed in the grain bulk. Long-term lack of oxygen causes the death of stored-grain insects.	To kill the stored-grain insects, the phosphine fumigant was forced to disperse and distribut uniformly in the grain bulk rapidly by recirculation fumigation device.
Operation evaluation	Simple operation, small in size, move easily, need no specific person to look after, relatively high requirement in depot gas tightness.	Complex operation, high requirement in depot gas tightness.	Simple operation, relatively low requirement in depot gas tightness.

Technology / Content	N_2 CA storage	CO_2 CA storage	PRFPS
Cost	Middle-cost, Abundant in raw material, High power-consumption,	High-cost, expensive CO_2, high power-consumption,	Low-cost, inexpensive fumigant.
Pollution	Pollution-free, Residue-free, No toxic side effects	No pollution and residues to stored-grain, mass inhalation may result in acidosis, CO_2 is a kind of greenhouse effect substance	With pollution and residues to stored-grain, with pollution to air and water resources, long-term use may result in occupational disease.
Equipment corrosion	Stable, No corrosion	some corrosion, water-soluble	corrosion to mental equipment and grain monitoring-control system.
Comprehensive assessment	Small economic input, environment-friendly, good effect of insect control and freshness-Preservation	Relatively big one-off input, good effect of insect control and freshness-Preservation	With pollution and residues, good effect of insect control, no function of freshness-Preservation

4.4 Economic cost comparison among different kind of stored-grain insects control technologies

Table 4. Economic cost comparison of N_2 CA storage, CO_2 CA storage, and PRFPS

Technology / Content	N_2 CA storage	CO_2 CA storage	PRFPS
Depreciation expense	20,000 RMB for 12 depots, according to depreciation period of 10 years, 2,000 RMB every year, 1667 RMB per depot every year	400,0000 RMB for 18 depots, according to depreciation period of 20 years, 20,0000 RMB every year, 11,111 RMB per depot every year	12,0000 RMB for 18 depots, according to 10 depreciation period of 10 years, 1,2000 RMB every year, 667 RMB per depot every year
Sealing expense	Design of horizontal warehouse sealing, 386 RMB/depot/year	500 RMB per depot, for construction of whole depot gas tightness	386 RMB per depot every year, for sealing
Chemical expense	None (Air as raw material)	4200 RMB, 6 tonnes of CO_2 for each depot, 700 RMB per tonne CO_2	400 RMB, 2 kilograms of Alp and 200 kilograms of CO_2 for each depot
Electricity expense	1900 RMB each depot	250 RMB each depot	Not counting
Other expense	No	No	Nutrition fee, 200 RMB
Cost on per tone grain every year	1.41	5.71	0.59
Total cost of each depot	1667 + 386 + 1900 = 3953	11111 + 500 + 4200 + 250 = 16061	667 + 386 + 400 + 200 = 1653

The result showed that the cost of N_2 CA storage was only a quarter of the cost of CO_2 CA storage.

5 Discussion

N_2 CA storage and CO_2 CA storage are each part of the development trend of green CA grain storage. N_2 CA storage was applied in our depot, Nanjing depot of state grain, in 2004 for the first time, and was being phased in our depot. N_2 CA storage had many obvious advantages at this stage. Compared to the CO_2 CA storage, the N_2 CA storage had the same ability to control the stored-grain insects, but its cost was only a quarter of the cost of CO_2 CA storage. In addition, clean N_2 won't create any pollution and corrosion, in contrast, it realized green grain storage and increased the value of product.

The N_2 CA storage developed by Nanjing depot of state grain, with advantages of small size high-purity nitrogen generator, easy operation, good insect control, low cost, was a new technology focused on the actual situation of the grain depot. This technology was applicable to full-bin application, especially for depots with a dispersion network or a re-circulation network, and was also applicable to poor air-tightness depot after low-cost air-tightness reform. The N_2 CA storage, having general practical applicability, was applicable to not only common flat warehouses, but also large granaries such as silos and silo bins and would have a bright future in the domain of green grain storage.

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